Generation and Evolution of Internal Waves in Luzon Strait

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LONG-TERM GOALS

Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes—i.e., internal tides, inertial waves, nonlinear internal waves (NLIWs), and turbulence mixing—in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty. For this study, our focus is on generation, propagation, evolution, and dissipation of small-scale internal waves and internal tides as the Kuroshio and barotropic tides interact with the two prominent submarine ridges in Luzon Strait.

OBJECTIVES

The primary objectives of this observational program are to quantify 1) the generation of NLIWs and internal tides in the vicinity of Luzon Strait, 2) the energy flux of NLIWs and internal tides into the Pacific Ocean and South China Sea (SCS), 3) the effects of the Kuroshio on the generation and propagation of NLIWs and internal tides, 4) the seasonal variation of NLIWs and internal tides, and 5) to study other small-scale processes, e.g., hydraulics and instabilities along internal tidal beams and at the Kuroshio front.

APPROACH

Far-field: Full water-column velocity and temperature observations were taken using one subsurface mooring with a near-bottom upward-looking 75-kHz ADCP and one subsurface mooring with a series of CTD sensors at a sampling rate of $\Delta t = 1$ min, capable of measuring internal tides and NLIWs, on the continental slope east of Dongsha Island, ~200 n mi west of Luzon Strait.

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Near-field: In the Luzon Strait, observations were taken using the combined 600-m-long towed CTD chain equipped with 40 CTD sensors and the Doppler sonar on the R/V *Revelle*. These instruments took high-frequency, Δt <1 min, and high vertical resolution, Δz = 5–20 m, measurements of CTD and oceanic velocity from near the surface to ~600-m depth.

WORK COMPLETED

One surface-buoy mooring (TC1), one subsurface mooring (TC2) , and two bottom pressure moorings (TC1-BPR and TC2-BPR) were deployed on the Dongsha slope from R/V *Ocean Researcher 1* of Taiwan on 27–31 May 2011. The surface and subsurface moorings were placed 6 km apart on the slope. Three ADCPs, fourteen CTD sensors, and three temperature loggers were equipped on the surface mooring (TC1). The subsurface mooring (TC2) was equipped with one Long Ranger, ten temperature sensors, and three CTD sensors (Fig. 1). On 1–6 June 2011 the surface and subsurface moorings were recovered by the Taiwanese R/V *Ocean Researcher 2*. The subsurface mooring was redeployed with an upward-looking 75-kHz Long Ranger, without temperature or CTD sensors. It was recovered in August 2011 by the R/V *Ocean Researcher 3*. The data analysis is in progress.

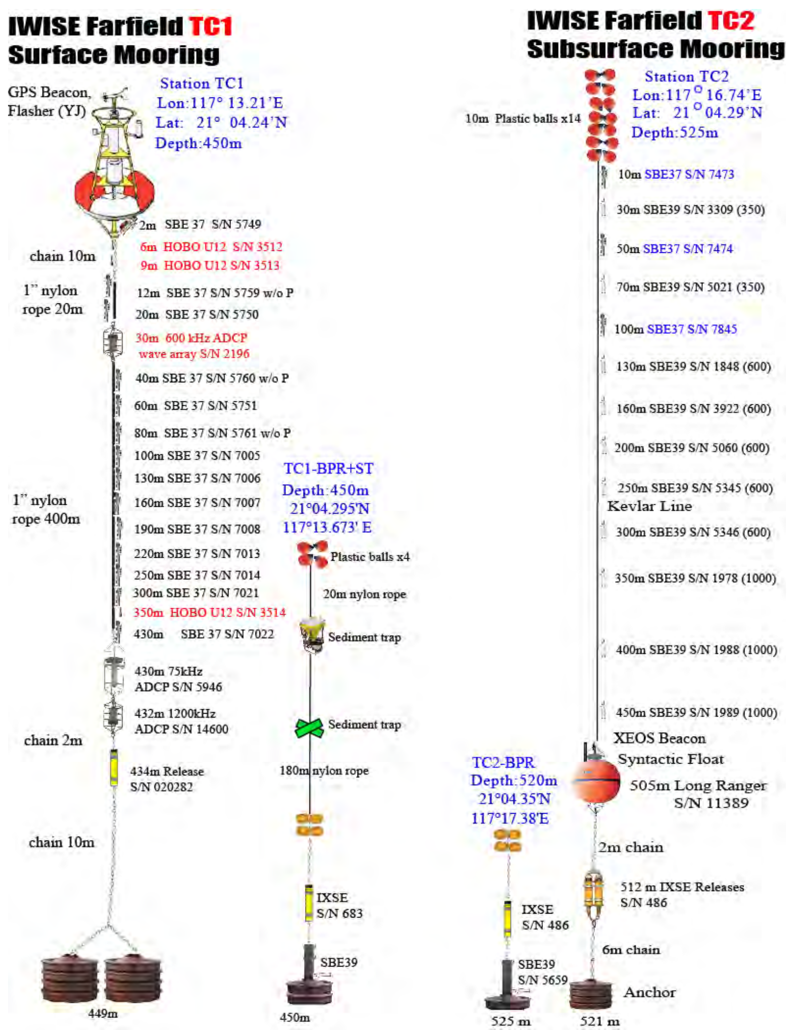

Figure 1. Configuration of far-field moorings deployed on the Dongsha slope.

From 25 July through 4 August 2011, we conducted an intensive survey in the Luzon Strait using a 600-m-long towed system equipped with 20–40 CTD sensors (Fig. 2). The primary scientific objectives of this cruise are 1) to measure nonlinear internal waves in Babuayn channel (Fig. 3), 2) to measure lee waves behind the sill west of Babuyan Channel, 3) to quantify internal tide generation at the southern Luzon Strait, and 4) to measure internal tide evolution at the southern Luzon Strait. All CTD sensors take samples of temperature, salinity and pressure at a 10-s interval.

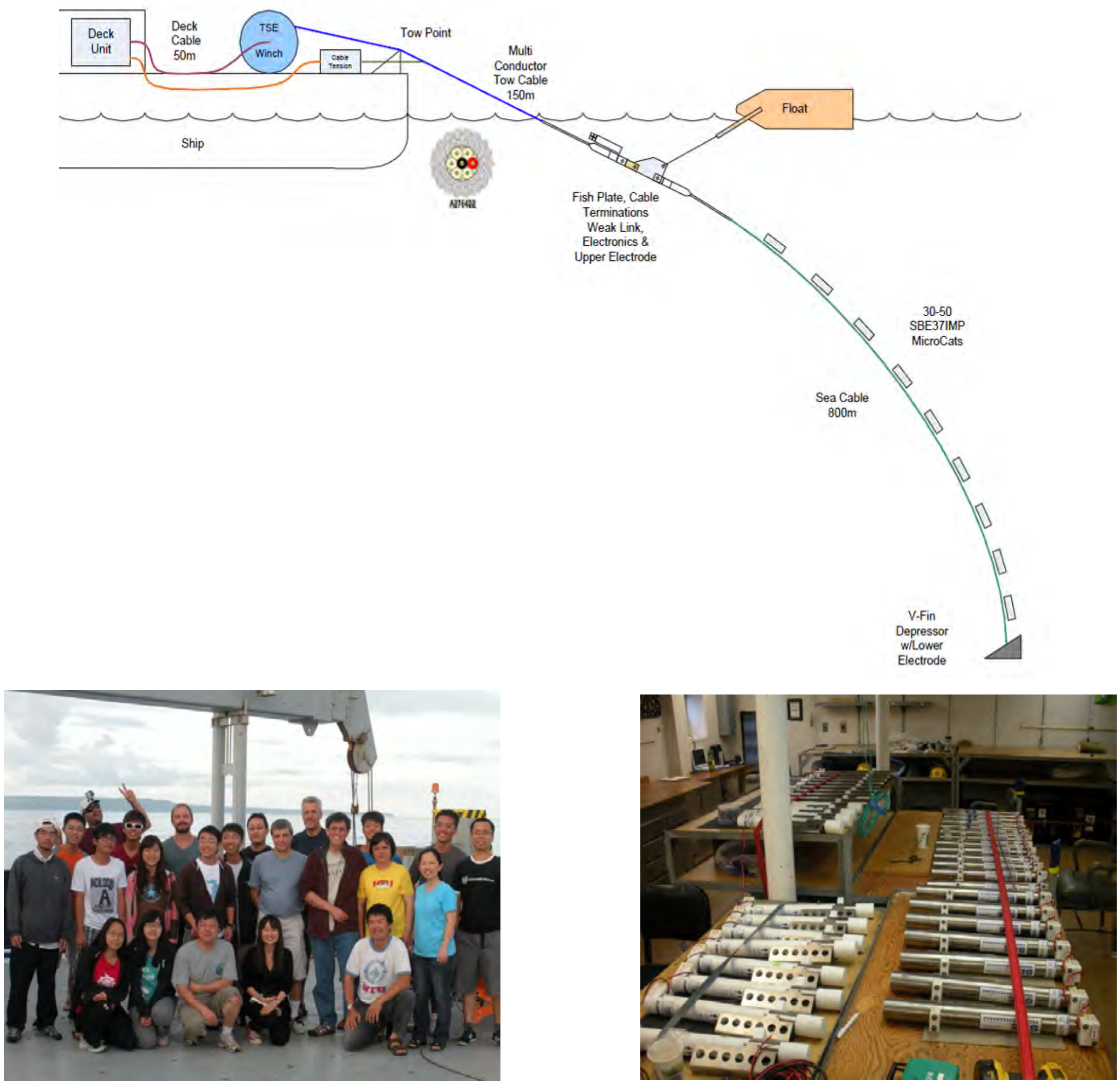

Figure 2. Schematic diagram of the towed CTD array (top panel). For the 2011 IWISE near-field cruise, 40 inductive SeaBird SBE37 CTD sensors (bottom right panel) were mounted on a 600-m sea cable and provided real-time transmission of data. The typical towing speed was 2–4 kt. Fifteen students and engineers from Taiwan and scientists and engineers from the U.S. participated in this cruise (bottom left panel).

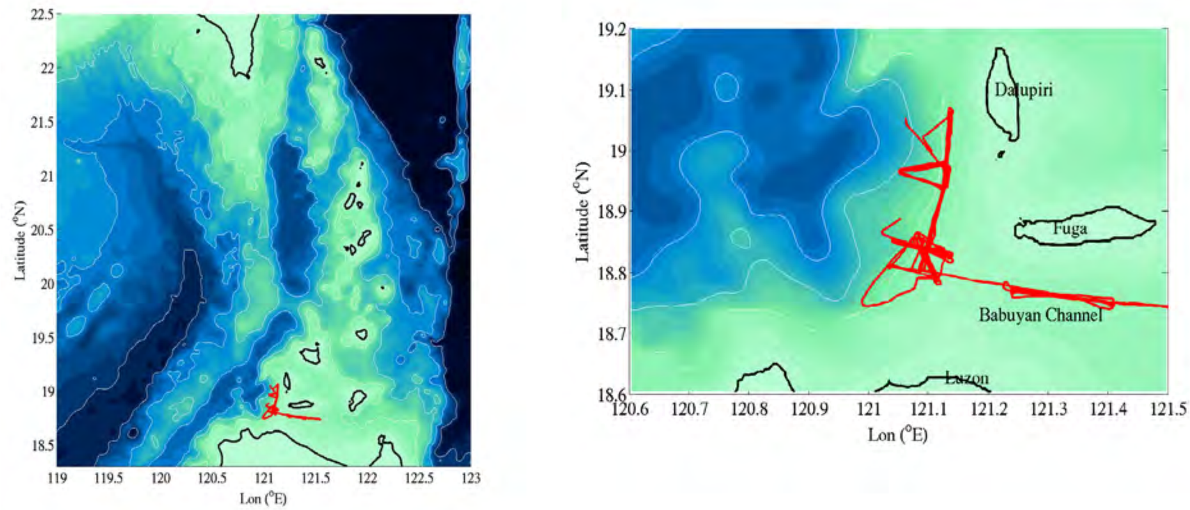

Figure 3: IWISE R/V* Roger Revelle *cruise #RR1111 general operation area of towed CTD observation (left panel). Towed CTD observations within Babuyan Channel and west of the slope of Fuga and Dalupiri islands (right panel).

RESULTS

In Babuyan Channel trains of small-scale internal waves were observed with vertical displacements of 10–20 m (Fig. 4). Surface manifestation of similar waves has been observed frequently in SAR and MODIS images.

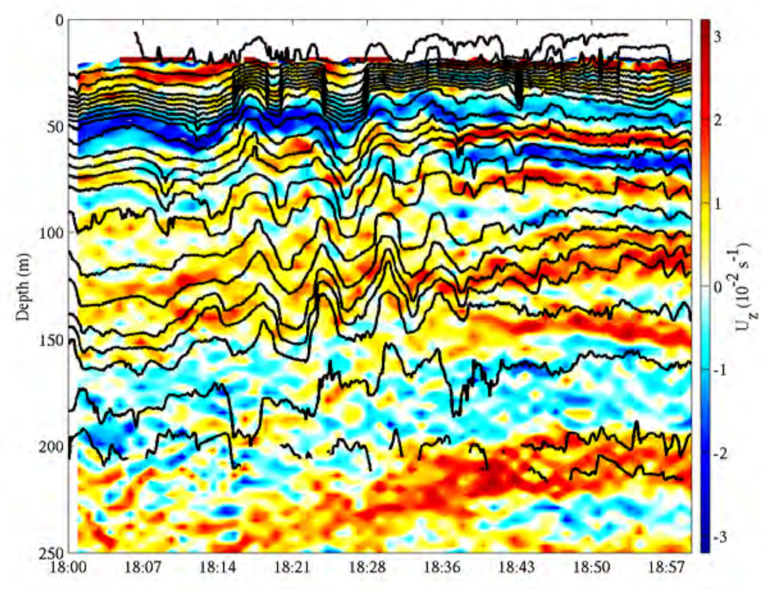

Figure 4: A wave train in Babuyan Channel was observed by a real-time towed CTD array. Color contours are vertical shear of zonal current taken from the HDSS 140-kHz ADCP and black contour lines are isopycnals.

Hydraulic jump features were observed west of the channel between Dalupiri and Fuga islands. One example is shown in Fig. 5. Mixed water of >100-m vertical scale existed between 150 m and 300 m. Strong salinity anomalies were found in the upper 150 m (bottom left panel).

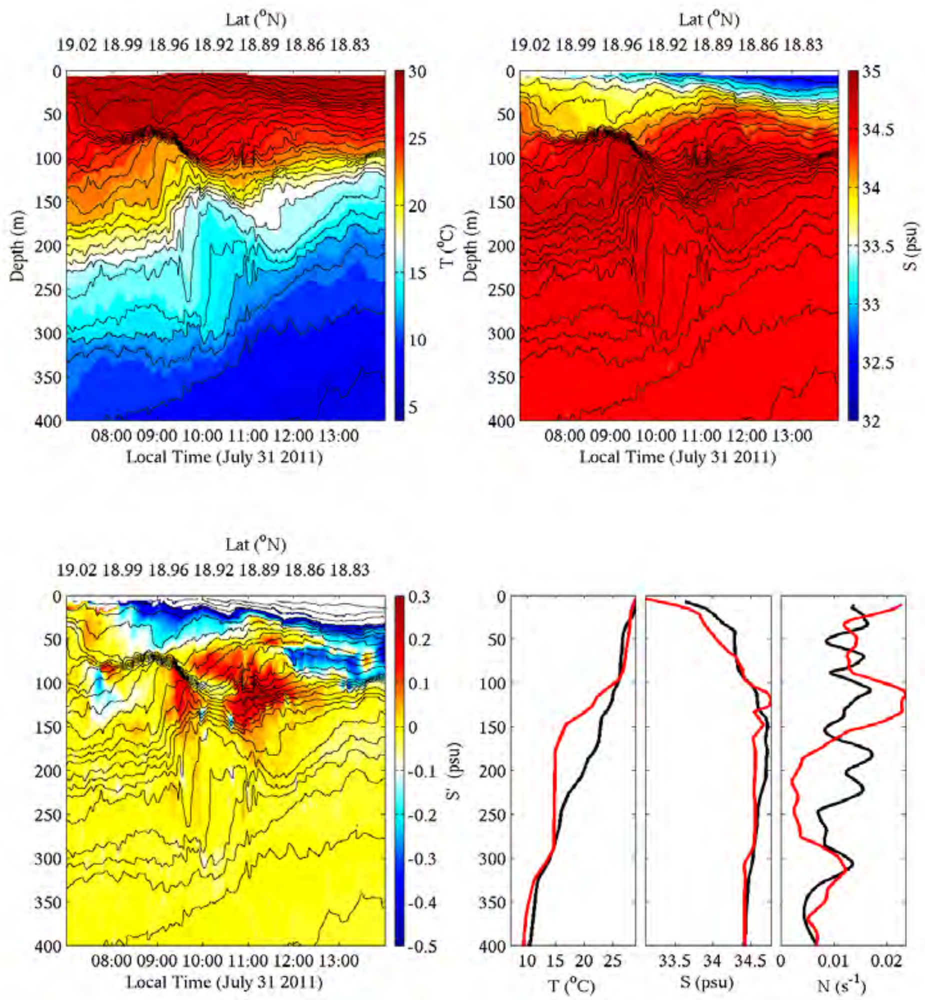

Figure 5: Example of hydraulic jump feature west of the channel between Dalupiri and Fuga islands. The color shadings in the top two panels show the salinity and temperature, and the contour lines represent isopycnals. In the bottom left panel, the color shading shows the salinity anomaly referenced to the T–S relation at 07:00 on 31 July 2011, and the contour lines represent isopycnals. The bottom right group of three panels shows vertical profiles of temperature, salinity and buoyancy frequency at 07:00 (black curves) and in the middle of hydraulic jump (red curves).

IMPACT/APPLICATION

Numerical models suggest strong internal tides are generated as barotropic tides interact with two prominent submarine ridges in Luzon Strait. These internal tides are thought to be the sources of nonlinear internal waves often observed in the South China Sea. The strength of internal tides is modulated by the barotropic tidal forcing, the strength of the Kuroshio current, the background stratification and the strength of the Kuroshio front. It is important to quantify the barotropic to baroclinic tidal energy conversion, dissipation within the Luzon Strait, the energy fluxes toward the South China Sea and Pacific Ocean, and the ultimate fate of the internal tidal energy.

RELATED PROJECTS

Process Study of Oceanic Responses to Typhoons Using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of ITOP DRI: We study the dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific using long-term mooring observations and an array of EM-APEX floats. Pacific typhoons may cause cold pools on the continental shelf of the East China Sea. The cold pool dynamics are likely related to the Kuroshio and its intrusion as well as the shelf/slope oceanic processes.